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MEMORANDUM REPORT ARBRL-MR-03260

THE EFFECT OF PROPELLANT COMPOSITION ON SECONDARY MUZZLE BLAST OVERPRESSURE

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April 1983

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: MEMORANDUM REPORT ARBRL-MR-03260	2. GOVT ACCESSION NO.
	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): THE EFFECT OF PROPELLANT COMPOSITION ON SECONDARY MUZZLE BLAST OVERPRESSURE	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): George E. Keller	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: US Army Ballistic Research Laboratory, ATTN: DRDAR-BLI, Aberdeen Proving Ground, MD 21005	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 1L161102AH43
11. CONTROLLING OFFICE NAME AND ADDRESS: US Army Armament Research and Development Command, US Army Ballistic Research Laboratory(DRDAR-BLA-S), Aberdeen Proving Ground, MD 21005	12. REPORT DATE: April 1983
	13. NUMBER OF PAGES: 53
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Muzzle Flash
Muzzle Blast
Propellant
Interior Ballistics

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) mb

Secondary muzzle flash results from the reignition of a mixture of fuel-rich exhaust gases and entrained air. This combustion process, which leads to energy released as light, also leads to acoustic energy release - noise. The additional blast overpressure resulting from secondary flash is here referred to as secondary blast. The availability of new observational data and a new flash prediction code permits insight into the link between secondary flash and secondary blast and into the possible suppression of both

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by judicious choice of propellant.

Extensive tank-gun firing data have recently been gathered on candidate low-vulnerability (LOVA) propellants. These data included high-speed films, blast overpressure measurements, and measurements of visible illumination from the flash. All of the propellant candidates were fuel-rich, and without a chemical suppressant they could be expected to flash in these tank-gun-firing situations. Three candidates, however, exhibited a significantly brighter visible secondary flash than the others. We found we could correlate the brighter flash with the expected products of their combustion; more important, the brighter flash correlated well with a more intense secondary blast. Thus, the link between secondary flash and secondary blast is reinforced.

Further, we recently obtained the Muzzle Exhaust Flow Field (MEFF) flash prediction model. We found that MEFF has some limitations, such as not being able to be used to simulate firings for which the ratio of propellant charge weight to projectile weight is not small, so that it could not be used to simulate our tank-gun firings. However, it includes detailed time-dependent chemistry, so that it can be used to predict the effects of propellant composition on the probability of secondary flash and secondary blast of artillery weapons. When we ran MEFF for applications of these candidate propellants in artillery situations, we found that none should flash. We concluded that the low flame temperatures of the LOVA candidate propellants were responsible for eliminating secondary flash in these artillery applications.

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I. INTRODUCTION

Secondary muzzle flash results from the reignition of a mixture of fuel-rich exhaust gases and entrained air. Three kinds of factors affect secondary muzzle flash. The first, chemical factors, include the presence of flash suppressant in the charge, the flame temperature of the propellant, and the chemical composition of the propellant. Physical factors include the exit condition of the propellant gas (temperature, pressure, and velocity) and the location and strength of shock in the muzzle flow. Mechanical factors which affect secondary muzzle flash include both the intentional effects of flash hiders and the unintentional effects of muzzle brakes. The work of Carfagno[1] and his coworkers did much to identify the causes of secondary flash.

Secondary muzzle flash has always been viewed as undesirable because it identifies the location of the gun and because it reduces the night vision of the gun crew. More recently, however, it has been realized that the combustion which leads to the release of optical energy (IR, visible, and/or UV) also leads to acoustic energy release - noise. The suppression of secondary flash thus becomes an important means of reducing the blast noise of the weapon.

Historically, flash has been suppressed (when it was possible) using mechanical "flash hiders" (slotted, cone shaped, etc.) or chemical salts (usually a potassium or sodium compound). The former method is effective for small arms, but it is considered too cumbersome for large caliber weapons. The latter works sometimes, but yields an accompanying smoke cloud, which can be quite detrimental in some situations. The use of propellants with lower flame temperatures has worked to reduce flash, when the chamber of the weapon is large enough for the increased charge weight. Recently, cases of inadvertant secondary flash initiation by muzzle brakes have been documented.[2]

The testing of a number of candidate low-vulnerability (LOVA) propellants in our laboratory - the tests primarily for measuring interior ballistic performance - afforded an opportunity for flash and blast observations for several propellants with different chemical compositions. This paper discusses those flash and blast measurements in detail, some of the surprises, and our conclusions.

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1. S. P. Carfagno, "Handbook on Gun Flash," Franklin Institute Report, Contract No. DA-36-034-514-ORD-78RD, Nov 1961 (AD327051).

2. E. M. Schmidt, "Gun Muzzle Flash and Associated Pressure Disturbances," AIAA Paper 81-1109 (1981).

We recently acquired a new flash prediction code, the Muzzle Exhaust Flow Field (MEFF) code.[3] It incorporates detailed, time-dependent chemistry, so we were interested to see what it would predict for applications of these cool LOVA propellants, with their different chemical compositions, in artillery situations. These predictions are compared with flash predictions by the May/Einstein method.[4]

II. FLASH AND BLAST MEASUREMENTS

A. General

The interior ballistic evaluation of the candidate LOVA propellants was principally conducted at BRL's Large Caliber Firing Facility (Range 18) using a highly instrumented 105-mm M68 tank gun. Our approach was to establish baseline performance with a reference lot of M30 propellant and then evaluate each candidate LOVA propellant, using the M30 performance as a standard. The test series for each LOVA candidate began with charge establishment to arrive at 420 MPa maximum pressure at ambient temperature. Candidate LOVA propellants evaluated included PU/HMX, CTBN/HMX, HTPB/HMX, CAB/RDX, CA/RDX, Kraton/RDX, and EC/NC/RDX. Details of the propellant compositions are in Appendix A. Some detailed ballistic data are listed in Appendix B. Additional details of the measurements are available in a previous JANNAF paper.[5]

Figure 1 shows the experimental setup. The principal flash measurement which we employed was the measurement of the luminous intensity of the flash. It was monitored with an EG&G Model 450 Photometer set to measure the luminance of the secondary flash directly. The photometer was fitted with a CIE standard filter, so the wavelength response of the instrument was approximately that of the human eye. High-speed color photography was also used to document the flash. The camera was set to one side of the gun muzzle, with a field of view approximately perpendicular to the flight of the projectile. The framing rate was set at 1000 frames per second. Blast overpressures were measured with a PCB 113A21 gage installed flush with the top surface of a lead brick, which was itself set flush with the surface of the ground. The gage was 1.2 meters to the front and 3.4 meters to the side of the 105-mm gun muzzle.

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3. V. Yousefian, "Muzzle Flash Onset," ARI-RR-236, Aerodyne Research, Inc., Billerica, MA, Nov 1980. Also available as ARBRL-CR-00477, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, Feb 82 (AD B063573L).

4. I. W. May and S. I. Einstein, "Prediction of Gun Muzzle Flash," ARBRL-TR-02229, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, March 1980 (AD A083888).

5. R. W. Deas, G. E. Keller, and J. J. Rocchio, "The Interior Ballistic Performance of Low Vulnerability Ammunition (LOVA)," 1981 JANNAF Propulsion Meeting, 26-28 May 1981, New Orleans, LA, CPIA Pub. 340, Vol III, pp 437-477.

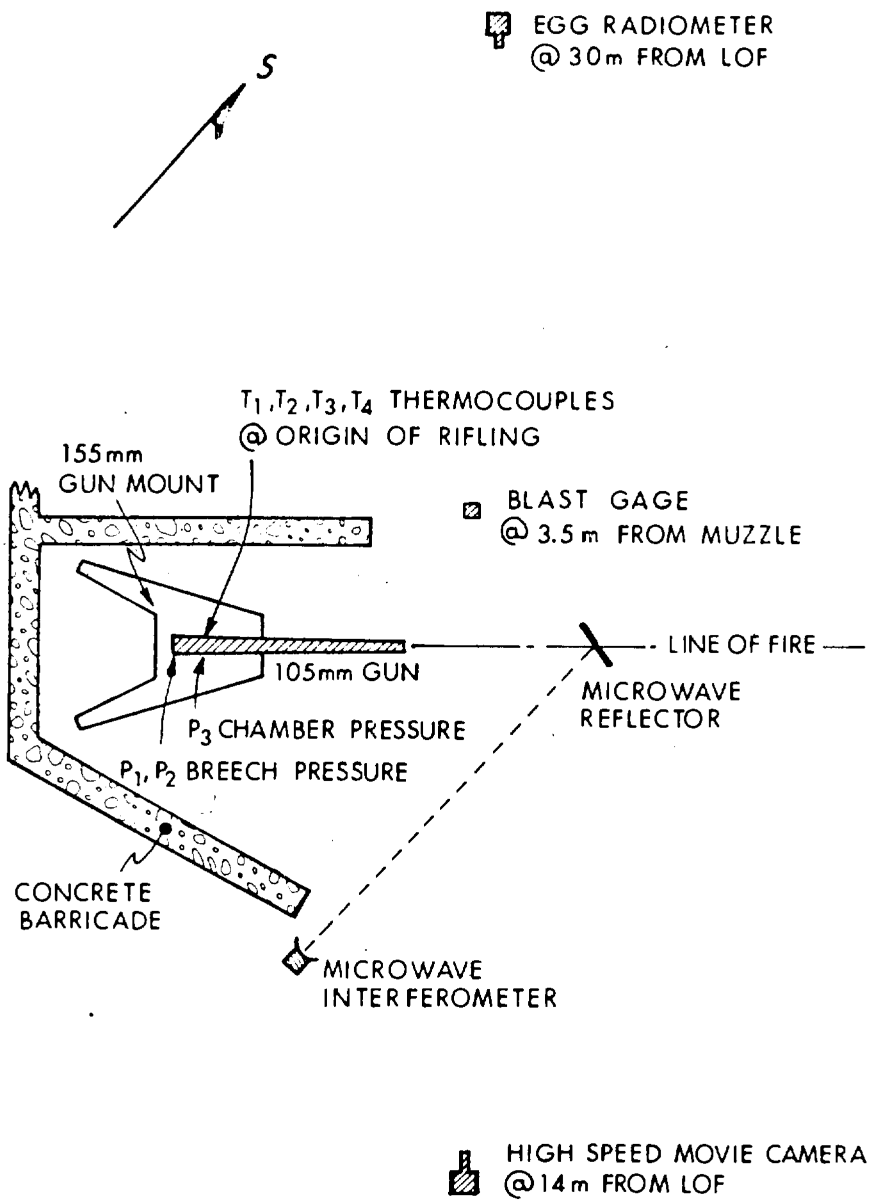

Figure 1. Schematic Plan of Experimental Setup

Both CA/RDX and CAB/RDX contained flash suppressant. Secondary flash occurred only once in the CA/RDX tests and only about half the time in the CAB/RDX tests. Secondary flash was observed for all the firings of all the other candidates, even CTBN/HMX, which had some suppressant. All of these propellants have low flame temperatures; secondary flash should be able to be suppressed by adding sufficient chemical suppressant to any of them. We believe that unsuppressed, they would all flash most of the time in tank gun firings, and that the flash of any could be suppressed with chemicals. This section of the paper will deal entirely with the intensity of the secondary flash, and not with flash suppression.

B. Flash

Figure 2 illustrates the visible illuminance due to a CAB/RDX firing which flashed. Figure 3 shows the dramatic difference when a CAB/RDX round had no secondary flash, but rather dense white smoke. The data recording system sensitivity was set to cope with a bright flash, but the smoke was only slightly brighter than the background radiation, so the signal is low and noisy. Figure 4 illustrates the much brighter flash of Kraton/RDX round. The data acquisition system establishes the zero time for each round, so that the times of any particular event (such as the flash) should not be compared for different rounds, while the times for different measurements made on the same firing can be compared. Table 1 summarizes the flash characteristics of the candidates, with M30 included as a reference point. The flash intensities (and standard deviations) have been transformed from illuminance (lux) into luminous intensity (candelas) by taking into account the size of the detector (in this case, 1 cm^2) and its distance from the line of travel of the projectile, about 30 m. Since not all CA/RDX or CAB/RDX rounds flashed, and since the number of rounds for which good records were obtained varied widely, the last column of the table shows the number of observations included in the statistical analysis. Note the absence of a correlation between intensity and flame temperature.

TABLE 1. A COMPARISON OF FLASH INTENSITIES

Propellant	Flame Temp (K)	Peak Secondary Flash Luminous Intensity (Mcd)	Total Number of Observations	Number of Observations of Flash
Kraton/RDX	2283	18.2 ± 1.2	11	11
CTBN/HMX	2379	13.8 ± .72	8	8
HTPB/HMX	2363	10.5 ± 1.6	4	4
CA/RDX	2438	>6	9	1
CAB/RDX	2499	3.95 ± .84	11	7
PU/HMX	2434	3.76 ± .64	8	8
M30	3010	2.79 ± .48	8	8
EC/NC/RDX	2536	2.69 ± .40	12	12

The gain settings of the measuring equipment was appropriate for CA/RDX rounds that did not flash, but when the one CA/RDX round did flash, the illuminance record was clipped. These records are sufficiently complicated that prediction of the peak height from a clipped record is risky; in this

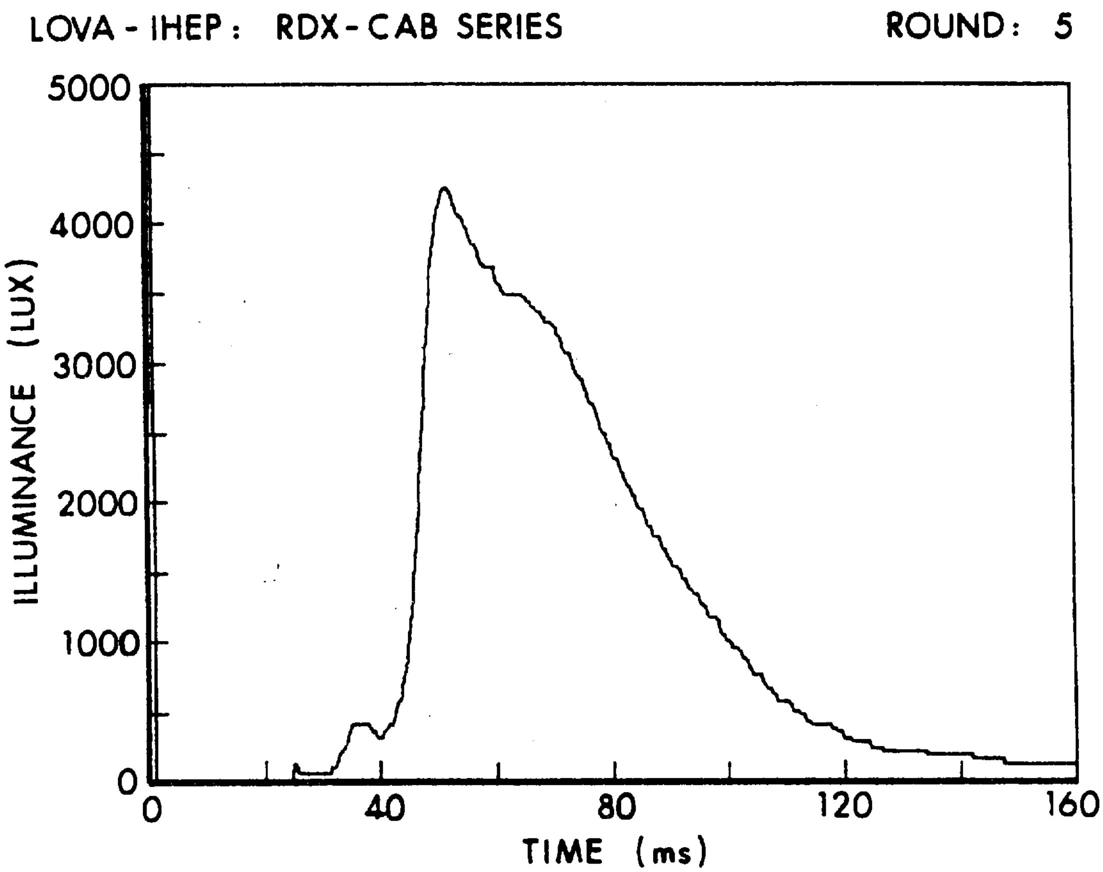

Figure 2. Visible Illuminance from a CAB/RDX Firing Which Flashed

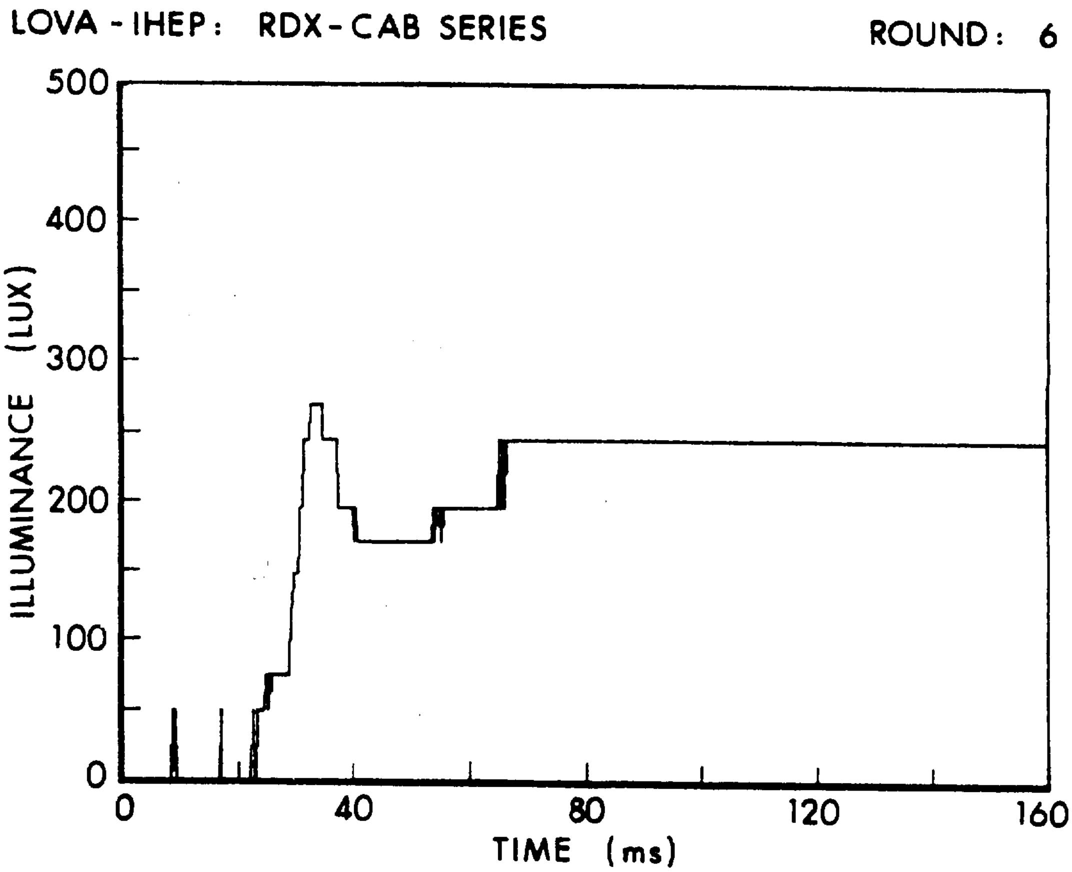

Figure 3. Visible Illuminance from a CAB/RDX Firing Which Did Not Flash

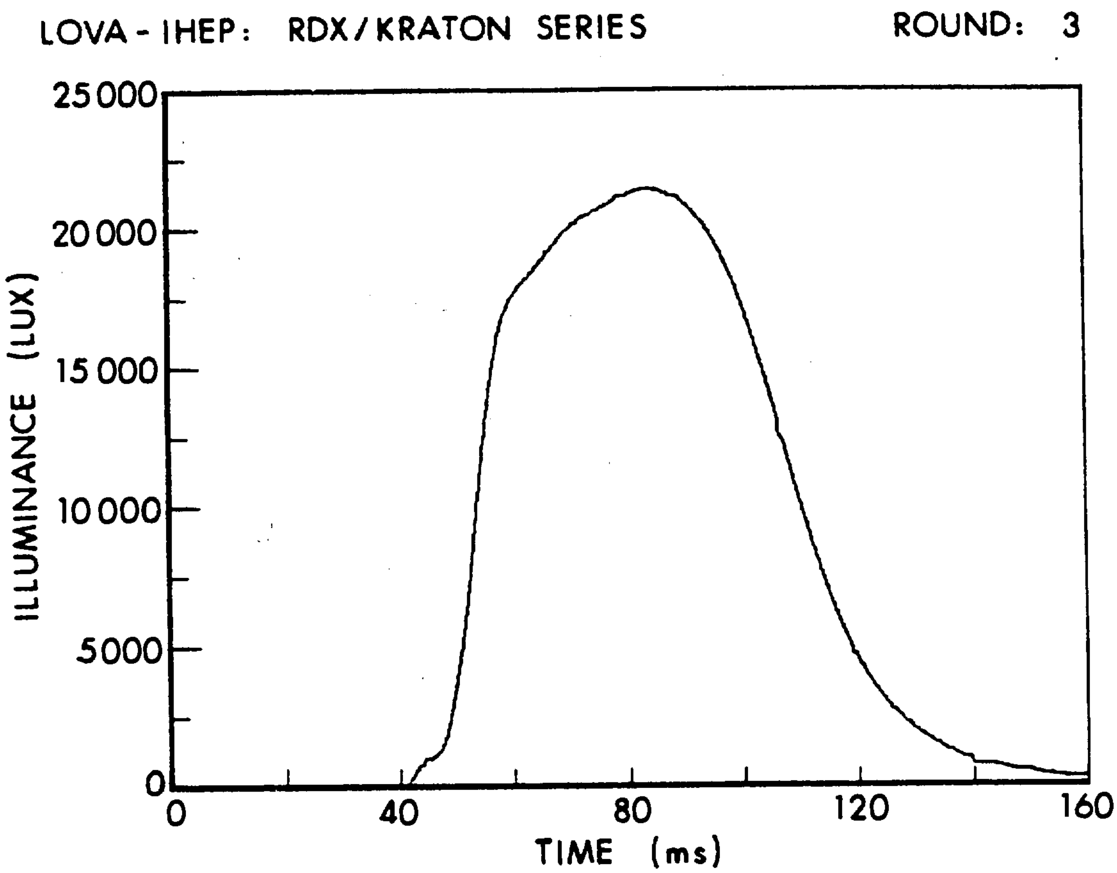

Figure 4. Visible Illuminance from a Kraton/RDX Firing Which Flashed

case, it is safe to say that luminous intensity for the CA/RDX round that flashed was greater than 6 Mcd and surely less than 10 Mcd.

From time to time, incompletely burned propellant, exiting the gun tube behind the projectile, has been blamed for initiating secondary flash. It is argued that if there were still-burning propellant grains in the muzzle gas/air mixture, they would provide ignition sites. In the case under consideration here, however, all the propellants which did not contain flash suppressant flashed, and those with flash suppressant flashed at least occasionally. Thus, there is no need to invoke still-burning propellant as an ignition source. It was interesting to note that our lumped-parameter interior ballistic calculations, some details of which are included as Appendix B, suggested that two of the three bright flashers had significant amounts of incompletely burned, and perhaps still-burning, propellant in the exit flow. Particles in the flow may lead to a brighter flash, as we shall see. Note that much effort is expended to be sure that fielded charges are designed so that all the propellant in a tank-gun charge or an artillery charge is burned in the tube, so that, when working with a fielded charge, unburned propellant should never be a problem.

The compositions of the candidates suggested the possibility of other correlations, however. We examined the expected products of each propellant using BLAKE,[6] first at the gun temperature and pressure associated with a typical gun loading density (0.2 g/cm^3) and then at the mean pressure and mean temperature predicted for the time of shot ejection for each separate propellant by a lumped-parameter interior ballistic model. The results of these calculations are included as Appendix C. While we found no correlation at all between bright flash and available fuel (CO, H_2, or CH_4), we did find a very strong correlation between the expected presence of solid carbonaceous residue and the peak flash intensity. Table 2 illustrates the calculated mole percentages.

TABLE 2. FLASH INTENSITY SOLID/CARBON CORRELATION

Propellant	Peak Secondary Flash Luminous Intensity (Mcd)	Solid Carbon at Gun Conditions (mole percent)	Solid Carbon at Time of Shot Ejection (mole percent)
Kraton/RDX	18.2	3.2	19.0
CTBN/HMX	13.8	0.8	18.4
HTPB/HMX	10.5	1.3	12.9
CA/RDX	>6	0.0	1.0
CAB/RDX	3.95	0.0	4.1
PU/HMX	3.76	0.0	7.7
M30	2.79	0.0	0.0
EC/NC/RDX	2.69	0.0	6.5

6. E. Freedman, "BLAKE - A Thermodynamic Code Based on TIGER: User's Guide and Manual," ARBRL-TR-02411, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1982 (AD A121259).

It should be noted that the "real" amount of solid carbonaceous residue is probably between the two percentages calculated; surely the reactions have continued beyond the gun conditions, but just as surely they have not reached equilibrium at the time of shot ejection. Nonetheless, the evidence suggests that a propellant which BLAKE predicts will have solid carbon present even under gun conditions is very likely to have a bright flash.

The idea that a fuel-rich flame burns more brightly is not new, of course. Even the fact that particles in the gun muzzle flow produce a brighter flash has been reported before. See, for example, the work of Klingenberg and Mach.[7]

C. Blast

Figure 5 illustrates the blast overpressure due to a CAB/RDX firing which did not flash (the same firing as for Figure 3). The primary blast overpressure is cleanly displayed, as is the rarefaction which follows. Absent from this trace, and all the others from this test series, are significant contributions from reflections from the weapon, the barrier, or the ground (which often complicate measurements made by gages mounted above the surface of the ground). The basic shape of the blast overpressure curve shown in Figure 5 is duplicated by all traces for CAB/RDX or CA/RDX for which there was no secondary flash.

Figure 6 shows the difference when a CAB/RDX firing flashed (the same firing as for Figure 2). After the primary overpressure peak and most of the rarefaction, there is a secondary positive overpressure (the maximum strength of which occurs at about 52 ms) and a secondary negative rarefaction (the maximum strength of which occurs at about 62 ms). The secondary positive overpressure and rarefactions are even clearer in Figure 7, which is for the same flashing Kraton/RDX shot that was illustrated in Figure 4.

The question has been raised as to whether the blast curve deviation which is here attributed to secondary blast could have been caused in whole or in part by radiative or convective heating of the blast gage as the burning cloud of exhaust gases sweeps by. Definitive tests have not, as of this writing, been done to exclude this possibility. However, if heating were a problem, it would have caused the largest effect for Kraton/RDX, for which the flash was brightest. Figure 4 shows that the radiative heating would not have peaked until just after 80 ms, but Figure 7 shows that the "secondary overpressure rarefaction recovery" is well advanced by then. For this reason, we believe that heating did not influence these results significantly, but the point remains to be proved.

The unusually clean pressure traces permitted quantifying the secondary blast overpressures. Several methods were considered, and the following method was chosen. A flashless CAB/RDX firing was traced for essential

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7. G. Klingenberg and H. Mach, "Investigation of Combustion Phenomena Associated with the Flow of Hot Propellant Gases - I: Spectroscopic Temperature Measurements Inside the Muzzle Flash of a Rifle," Combustion and Flame, 27, 163-176 (1976).

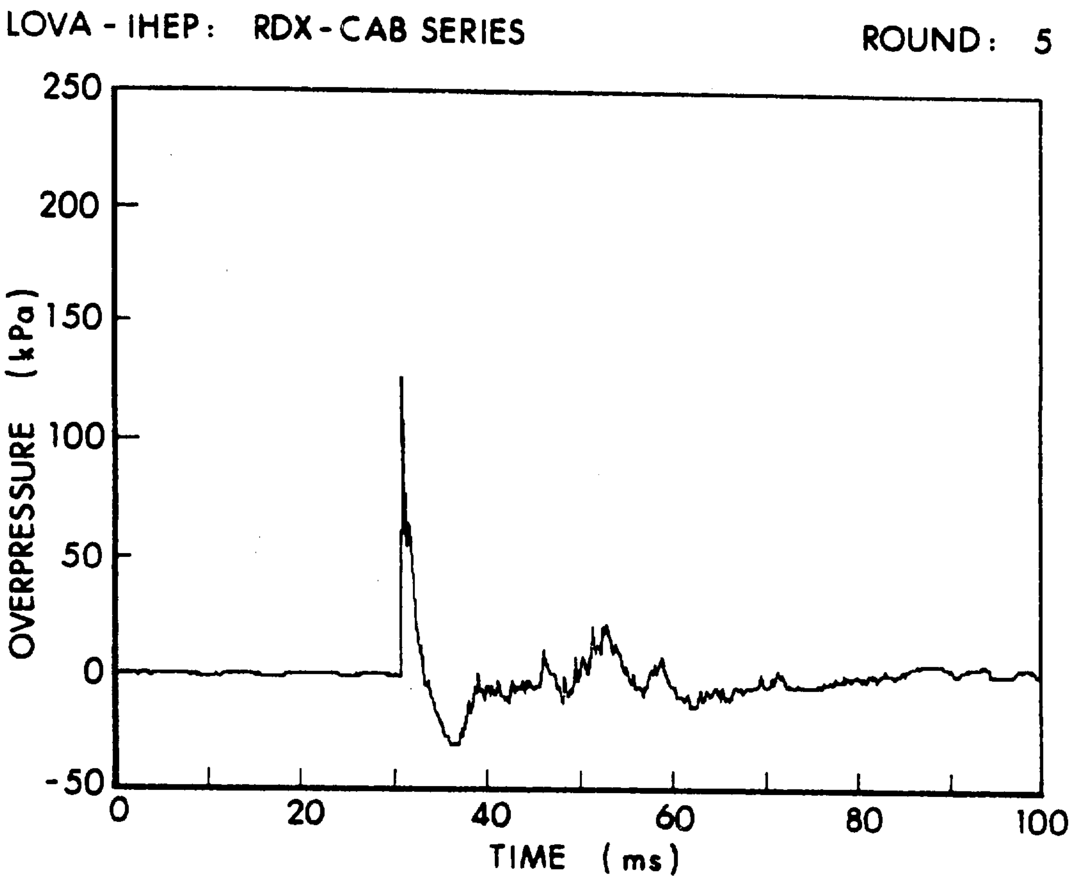

Figure 5. Blast Overpressure from a CAB/RDX Firing Which Flashed

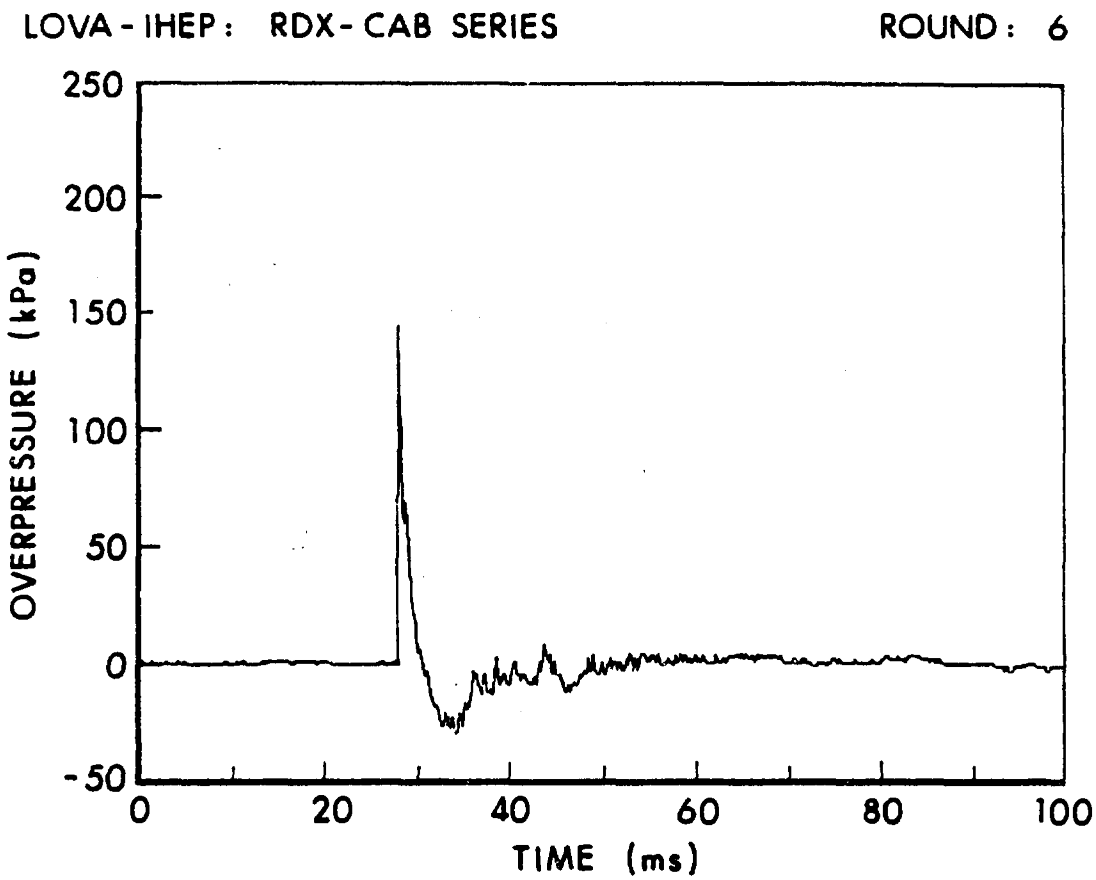

Figure 6. Blast Overpressure from a CAB/RDX Firing Which Did Not Flash

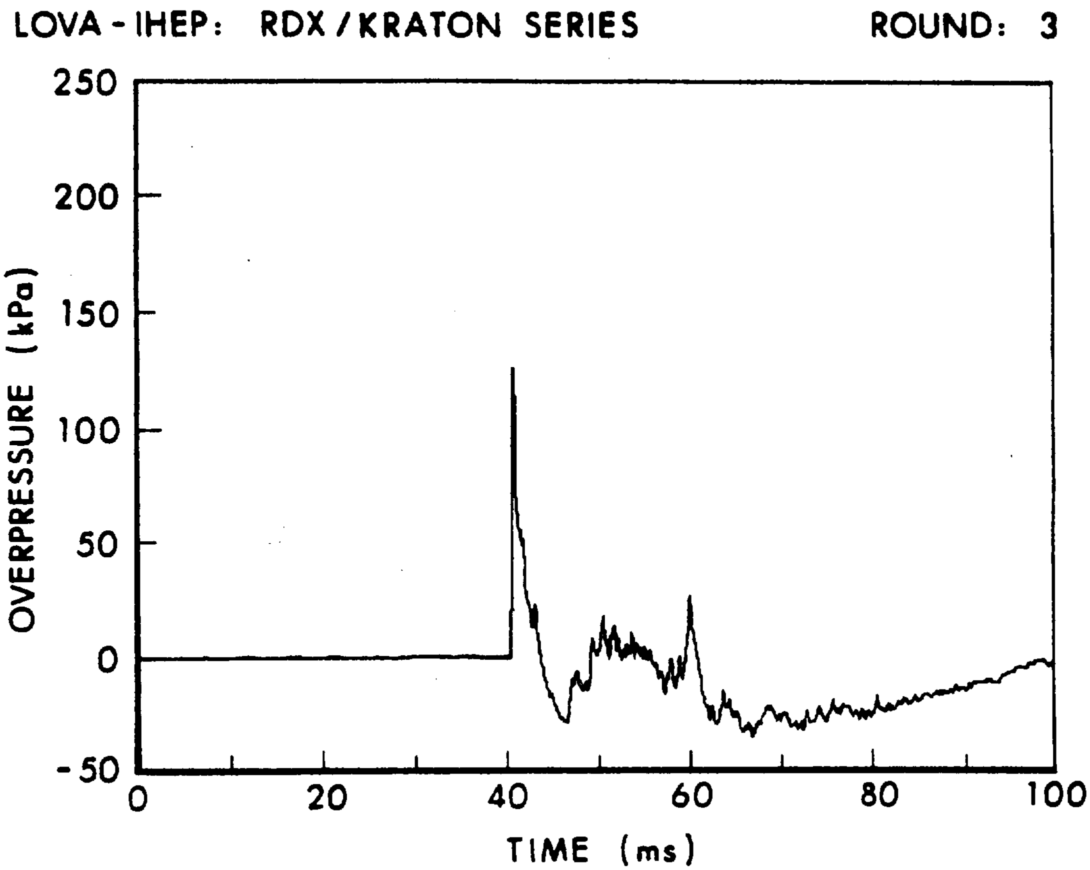

Figure 7. Blast Overpressure from a Kraton/RDX Firing Which Flashed

features (less the noise). Each record was then compared to this tracing, and the area of the overpressure curve above the flashless curve due to the second secondary blast was measured. Also, the area below the flashless curve, due to the rarefaction caused by the secondary blast, was measured. The data obtained are shown in Table 3, including standard deviations of the mean areas.

TABLE 3. SECONDARY BLAST

Propellant	Peak Secondary Flash Luminous Intensity (Mcd)	Area due to Secondary Overpressure (Pa s)	Area due to Secondary Rarefaction (Pa s)	Total Area due to Secondary Blast, (Pa s)	Number Blast Observations
Kraton/RDX	18.2	80 ± 18	879 ± 164	959 ± 152	12
CTBN/HMX	13.8	93 ± 23	540 ± 118	633 ± 99	13
HTPB/HMX	10.5	66 ± 1	537 ± 34	603 ± 33	2
CA/RDX	>6	54	205	259	1
CAB/RDX	3.95	68 ± 17	141 ± 61	209 ± 74	7
PU/HMX	3.76	76 ± 11	238 ± 40	315 ± 34	5
M30	2.79	59 ± 11	166 ± 45	225 ± 42	8
EC/NC/RDX	2.69	50 ± 6	152 ± 25	203 ± 22	11

Note the very strong correlation between the luminous intensity of the secondary flash and the total area due to the corresponding secondary blast. The same three candidates that probably have more solid carbon in their muzzle exit flows have both enhanced flash and more intense secondary blast.

The blast gage used in this study was not located in the crew area, nor could it have been so located, because of the protective barricades at our firing site. Thus, our data cannot be related directly to the effect that the observed secondary blast would have on the gun crew. However, it is safe to say that the secondary blast would increase the B-duration (MIL-STD-1474B[8]) of the entire blast envelope, and that would prolong its effect on the crew.

D. Proposed Mechanistic Link

The strong correlations interrelating the probable presence of carbonaceous residue in the muzzle flow, the luminous intensity of the secondary flash, and the strength of the secondary blast led us to look for possible mechanisms which would link them all together, and indeed, such a mechanism has been proposed.

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8. "Military Standard Noise Limits for Army Materiel," MIL-STD-1474B(MI), 18 June 1979.

Moore and Weinberg[9] were seeking to account for the level of damage observed following unconfined vapor cloud explosions. The flame speeds needed were too slow to be due to detonations but too fast to be due to deflagrations. Moore and Weinberg suggested that radiation from a large enough body of particles in the flow could be sufficient to provide an extended ignition source, so that the deflagration would proceed much faster than usual, helped along by propagation of the ignition stimulus at the speed of light. Our observations of a larger-than-expected secondary blast being linked to the probable presence of particles in the flow could certainly be explained by just such a deflagration enhanced by extended ignition.

In any case, enhanced secondary flash and enhanced secondary blast, to the extent that they are caused by solid carbon particles in the muzzle flow, are problems that can be avoided by performing a relatively simple BLAKE calculation when the propellant composition is first proposed. If carbonaceous residue is predicted, the proposed composition should be changed.

III. FLASH PREDICTION CALCULATIONS

A. General

Having made observations of the flash of these candidate propellants in tank-gun firings, we were then curious to see what some of the available flash-prediction codes would have predicted for their flash performance. We were especially interested to see what the latest code, the Muzzle Exhaust Flow Field (MEFF) code,[3] would predict, since its advanced features include the handling of detailed chemistry.

We would liked to have applied MEFF directly to predictions of flash for tank-gun firings for the best comparison with the observations. However, we could not. MEFF uses the results of Corner[10] for calculating the flow out of the gun tube after the ejection of the projectile. Unfortunately, Corner neglects terms of the order of $(C/W)^2$, where C is the weight of the propelling charge and W is the weight of the projectile. In the case of tank guns, the ratio C/W is about 1, so that it cannot be neglected. Other multipliers may make these terms grow smaller even if C/W is not negligible, but we do not know of a solution to the equations which retains all the terms. Thus, we opted to do a study of flash prediction for these candidate propellants in artillery situations, a study which MEFF handled easily.

B. MEFF Calculations

The version of MEFF that we used is very close to that documented in Ref. 3, ARI-RR-236. Thirteen (13) atomic and molecular species are considered, including KO_2 and HO_2. These are linked by the "extended kinetics" reaction

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9. S. R. Moore and F. J. Weinberg, "High Propagation Rates of Explosions in Large Volumes of Gaseous Mixtures," Nature, 290, 39-40 (1981).

10. J. Corner, Theory of Interior Ballistics of Guns, John Wiley & Sons, New York (1950).

set of 25 reactions. After the work of Schmidt,[11] we have increased the diameter of the Mach disk, so that the multiplier in the equation which calculates the fraction of the propellant gases which pass through the Mach disk is 0.96 instead of the original 0.52 in MEFF. We have compared the results of several calculations with calculations done by V. Yousefian, who developed MEFF, to insure that our results are identical to his.[12]

MEFF has been quite successful in its predictions of secondary flash for several systems. It was exercised for a wide range of firings, from 8-in. howitzers down to 81-mm mortars, for situations in which no muzzle brakes were in use. For cases for which it had been observed that the system always flashed or never flashed, MEFF successfully predicted the flash/no flash condition. For a case for which it had been observed that the system sometimes flashed and sometimes did not, MEFF predicted that the case was borderline.[13]

We standardized on an interior ballistic calculation for the M109A1 howitzer, using the M203 charge (less its added salt bag) to fire an M483A1 projectile. We used the same burn rates for the propellants that had been used for the tank-gun work.[5] Grain dimensions and charge weights were chosen to match the peak pressure and muzzle velocity (808 m/s) of our "standard" calculation. It should be noted at the outset that these cooler propellants have less impetus, so that it would take larger charges to achieve the same ballistics, so that it might prove difficult or even impossible to load the calculated amounts into the chambers of available weapons. Nonetheless, the results are interesting.

Table 4 shows the results of MEFF calculations for four propellants, M30 with 1% suppressant (M30A1), M30 with 2% suppressant, Kraton/RDX with no suppressant, and PU/HMX with no suppressant. The two LOVA candidates were chosen from among all the LOVA candidates based on their chemical composition; for these two, no significant molecular species were generated that were not on the list of the 13 species that MEFF treats.

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11. E. M. Schmidt, "Secondary Combustion in Gun Exhaust Flows," ARBRL-TR-02373, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, Oct 1981 (AD A107312).

12. V. Yousefian, personal communication.

13. V. Yousefian, "Muzzle Flash Onset: An Algebraic Criterion and Further Validation of Muzzle Exhaust Flowfield Model," ARI-RR-296, Aerodyne Research, Inc., Billerica, MA, July 1982.

TABLE 4. MEFF FLASH PREDICTIONS

Propellant	Flash?
M30, 0% suppressant	yes, promptly
M30, 1% suppressant	yes, late
M30, 2% suppressant	no
Kraton/RDX (0% suppressant)	no
PU/HMX (0% suppressant)	no

These results are quite easy to see in Figure 8, which shows the centerline temperatures predicted for the several propellants by MEFF. The temperatures are plotted with respect to the distance downstream of the "initial plane," which corresponds roughly to the plane of the Mach disk and the reflected shocks. The huge temperature rises for M30 with 0% and with 1% suppressant are indicative of reignition of the propellant gases, now mixed with some air and shock heated. Note that by the time the flow has progressed 10 or 15 meters, there is no doubt that the M30 (0%) case is going to flash. For the case of M30 with 1% suppressant, the flow has progressed more than 25 meters before the result is obvious. Realistically, that is longer than one should probably believe the results of a steady calculation. On the other hand, observations of this system show it to be a borderline flasher. Fairly clearly, none of the other three propellants should lead to flash.

The curve on Figure 8 labeled "Kraton/RDX from a hot gun" is an attempt to compare Kraton/RDX with M30 as to their tendency to flash, given roughly similar initial conditions. For the calculation, the mean gas temperature was assumed to be the same as it had been for M30 with no suppressant, 1813 K (as could take place for a weapon with a much shorter barrel, for example). The result is that the Kraton/RDX/air mixture reignites as readily as M30/0%/air. Perhaps this is not surprising, for the LOVA candidates are fuel-rich, so that <u>if the LOVA propellant gases leave the gun hot</u>, they should ignite and flash.

It should be noted that all of these are calculations of systems without muzzle brakes. Schmidt has shown that the installation of a muzzle brake can exacerbate a flash problem, transforming a marginal flasher into a system that flashes every time.[2]

C. <u>May/Einstein Calculations</u>

We have compared the MEFF predictions with predictions made using the flash-prediction technique of Carfagno,[1] as corrected and improved by May and Einstein.[4] This procedure calculates the temperature of the muzzle gas/air mixture as a function of the fraction of entrained air in the mass of the mixture. When this temperature exceeds experimentally determined ignition

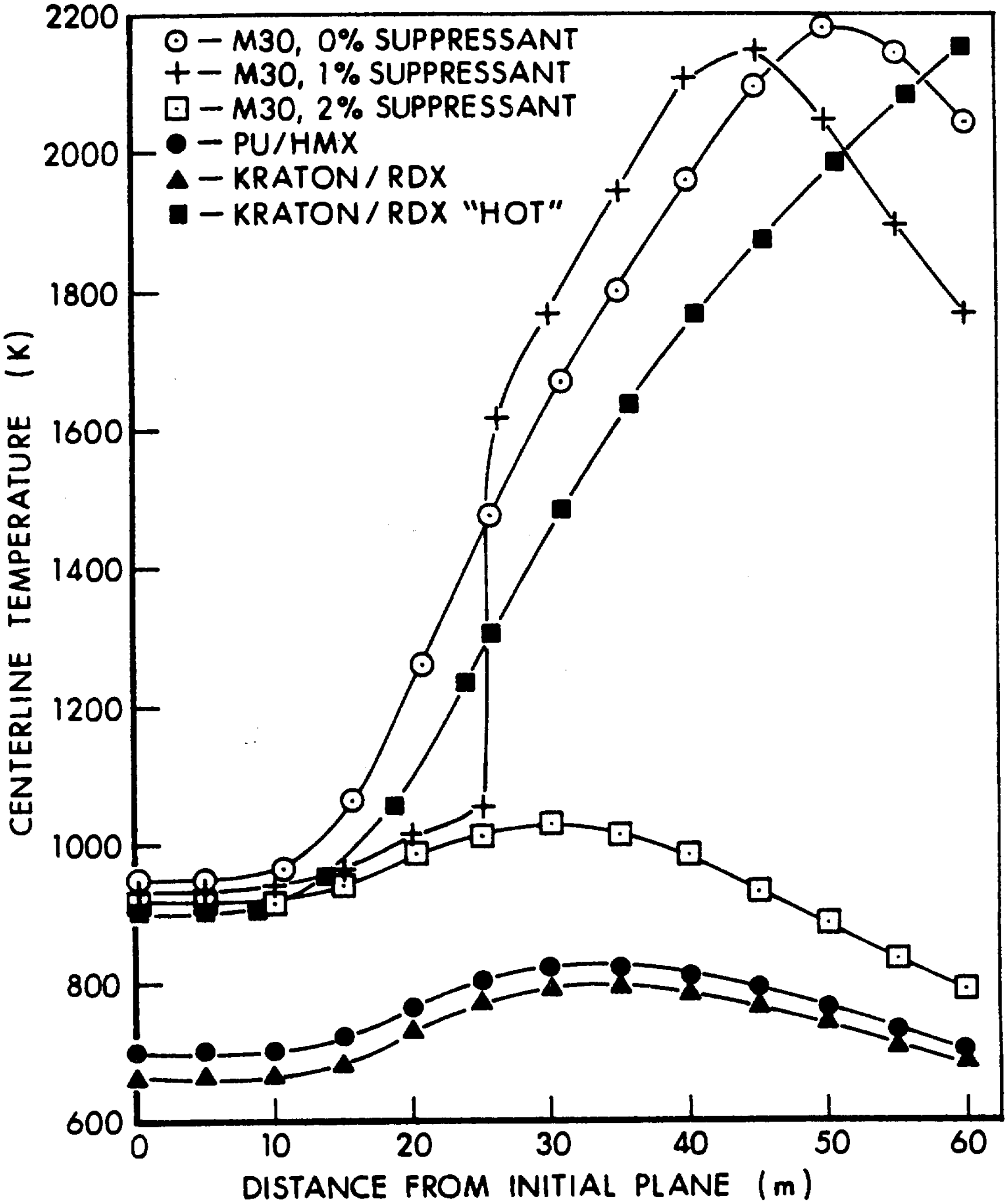

Figure 8. Centerline Temperatures Predicted for Several Propellants by MEFF

limits, flash is likely to occur. Table 5 is a guide for predicting whether reignition of the mixture will lead to secondary flash.[14] After a May/Einstein calculation is performed, so that the peak predicted mixture temperature is established, one looks on Table 5 at the row corresponding to the given percentage of suppressant and notes in which column the calculated temperature best fits.

TABLE 5. FLASH CRITERIA FOR ARTILLERY WEAPONS

Flash Suppressant	Occurrence of Secondary Flash		
%	Regularly	Marginal	Never
0	900 K	800 K	700 K
1	1125 K	1025 K	925 K
2	1225 K	1125 K	1025 K

The results of the May/Einstein flash prediction calculations are shown in Table 6.

TABLE 6. MAY/EINSTEIN FLASH PREDICTIONS

Propellant	Peak Predicted Mixture Temperature	Flash?
M30, 0% suppressant	1079 K	yes
M30, 1% suppressant	1067 K	marginal
M30, 2% suppressant	1057 K	no
Kraton/RDX (0% suppressant)	790 K	marginal
PU/HMX (0% suppressant)	819 K	marginal

D. Comparisons

Considering the differences in the two predictive codes, their agreement is impressive for M30, and it is quite acceptable for the LOVA candidates. The May/Einstein analysis suggests that Kraton/RDX and PU/HMX are not cool enough to be completely safe from secondary flash in artillery applications, while MEFF would predict that they would never flash. Lacking data, one cannot yet say which prediction is correct. One could infer, however, that a small amount of suppressant added to either LOVA candidate would eliminate any tendency to flash if they were used in artillery situations with no muzzle brake installed.

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IV. CONCLUSIONS

Extensive tank-gun firing data have been used to study the flash and blast characteristics of candidate low-vulnerability (LOVA) propellants. Three of the candidates exhibited a significantly brighter visible secondary flash than the others. This brighter visible secondary flash could be correlated with a more intense secondary blast. Both brighter flash and enhanced secondary blast could be correlated with larger predicted amounts of solid carbon particles in the muzzle exit flows for those propellants. Enhanced secondary flash and secondary blast from this source need not be tolerated, however, for a BLAKE calculation for the propellant candidate at the time that its chemical composition was being proposed would identify potential problems in this area.

Both the Muzzle Exhaust Flow Field (MEFF) flash prediction code and the May/Einstein flash prediction technique were used to predict the secondary flash potential of two of the LOVA candidates in artillery applications. It was found that there was little chance of their flashing, and that if they did, a little chemical suppressant would suppress the flash. These conclusions are valid for situations in which no muzzle brake is installed on the weapon; muzzle brakes are known to enhance the possibility of secondary flash.

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APPENDIX A

CHARACTERISTICS OF THE PROPELLANTS

For each propellant, BLAKE[6] was used to calculate the thermodynamic quantities from the propellant composition.

M30 Reference Propellant

Manufacturer: Radford Army Ammunition Plant
Lot: RAD 67878

Composition, % by wt.:

Nitrocellulose (12.6%)	27.61
Nitroglycerin	22.67
Nitroguanidine	47.96
Ethyl Centralite	1.49
Cryolite	0.27
Total	100.00
Graphite (Added)	0.17
Residual Volatiles	0.21

Flame Temperature: 3010 K
Impetus: 1076 J/g
Ratio of Specific Heats: 1.24
Covolume: 1.05 ml/g

PU/HMX Candidate Propellant

Manufacturer: Thiokol-Elkton
Lot: PVI-1909

Composition, % by wt.:

L-35 (polyether)	13.00
TMP	1.43
IPDI	5.57
HMX	80.00
Total	100.00

Flame Temperature: 2434 K
Impetus: 1038 J/g
Ratio of Specific Heats: 1.28
Covolume: 1.23 ml/g

EC/NC/RDX Candidate Propellant

Manufacturer: Naval Ordnance Station, Indian Head
Lot: Mix No. 890

Composition, % by wt.:

Ethyl Cellulose	11.7
Nitrocellulose (12.6%N)	7.4
Dibutyl Phthalate	6.7
Ethyl Centralite	0.7
RDX (Ground)	55.1
RDX (E)	18.4
Total	100.0
Tullanox (added)	0.515

Flame Temperature: 2536 K
Impetus: 1056 J/g
Ratio of Specific Heats: 1.28
Covolume: 1.21 ml/g

CAB/RDX Candidate Propellant

Manufacturer: Naval Ordnance Station, Indian Head
Lot: Mix No. 891

Composition, % by wt.:

Cellulose Acetate Butyrate	16.0
Triacetin	8.0
K_2SO_4	1.0
RDX (Ground)	75.0
Total	100.0

Flame Temperature: 2499 K
Impetus: 1018 J/g
Ratio of Specific Heats: 1.27
Covolume: 1.18 ml/g

Kraton/RDX Candidate Propellant

Manufacturer: Naval Ordnance Station, Indian Head
Lot: Mix Nos. 1059/1072

Composition, % by wt.:

Kraton G1652	9.95
Tufflo 6065	9.95
AO 2246	.10
RDX (Ground)	80.00
Total	100.00

Flame Temperature: 2283 K
Impetus: 971 J/g
Ratio of Specific Heats: 1.25
Covolume: 1.30 ml/g

CA/RDX Candidate Propellant

Manufacturer: Naval Ordnance Station, Indian Head
Lot: Mix Nos. 893/894

Composition, % by wt.:

Cellulose Acetate	16.0
Triacetin	8.0
K_2SO_4	1.0
RDX (Ground)	75.0
Total	100.0

Flame Temperature:	2548 K
Impetus:	999 J/g
Ratio of Specific Heats:	1.27
Covolume:	1.15 ml/g

CTBN/HMX Candidate Propellant

Manufacturer: Naval Ordnance Station, Indian Head
Lot: Mix 8221A

Composition, % by wt.:

CTBN	14.94
Vanox 13	.60
Graphite	1.00
Lecithin	.40
TP-95	1.20
KNO_3	1.00
ERL 0510	1.80
Fomrez C-2	.06
HMX	79.00
Total	100.00

Flame Temperature:	2379 K
Impetus:	1005 J/g
Ratio of Specific Heats:	1.27
Covolume:	1.28 ml/g

HTPB/HMX Candidate Propellant

Manufacturer: Naval Ordnance Station, Indian Head
Lots: Mix 8228 and Mix 8232

Composition, % by wt.:

R45M	14.04
618	.25
AO 2246	.25
L-14	2.85
Graphite	.50
XB 2826	.50
IPDI	1.24
PAPI 901	.37
HMX	80.00
Total	100.00

Flame Temperature:	2363 K
Impetus:	1008 J/g
Ratio of Specific Heats:	1.27
Covolume:	1.29 ml/g

APPENDIX B

BALLISTIC DATA

For each candidate propellant, lumped-parameter interior ballistic calculations were performed to match the mean performance. Some significant results from those calculations follow:

	M30	PU/HMX	EC/NC/RDX	CAB/RDX
Charge wt (kg)	5.62	5.53	5.58	5.94
Maximum breech pressure (MPa)	432	421	420	418
Muzzle velocity (m/s)	1505	1475	1487	1485
% of propellant burned	100.	100.	100.	99.7

	Kraton/RDX	CA/RDX	CTBN/HMX	HTPB/HMX
Charge wt (kg)	5.76	4.99	6.03	6.12
Maximum breech pressure (MPa)	409	427	432	418
Muzzle velocity (m/s)	1420	1424	1489	1438
% of propellant burned	95.2	100.	99.2	96.9

APPENDIX C

PROPELLANT PRODUCT CONSTITUENTS

For each of the candidate LOVA propellants and for M30, this appendix lists the concentrations of the constituents CO, H_2, CH_4, and solid carbon (soot or smoke), as calculated by the BLAKE[6] code, in the burning propellant gas/solid mixture. They are first calculated for the pressure and temperature that result from a "standard" charge loading density of 0.2 g/cc; these calculations are referred to as "gun" calculations. Then they are listed for the pressure and temperature at the muzzle at the moment of shot ejection when that particular propellant was used; these calculations are referred to as "muzzle" calculations.

	Gun Calculations		Muzzle Calculations	
	moles/kg of compound	mole % of total	moles/kg of compound	mole % of total
<u>M30</u>				
CO	11.8756	27.63	10.8591	25.32
H_2	5.59868	13.02	6.51051	15.18
CH_4	.000510	0.00	.026724	0.06
C(S)	0.0	0.00	0.0	0.00
<u>PU/HMX</u>				
CO	19.4297	37.87	8.76015	19.66
H_2	1.55467	3.03	5.94253	13.34
CH_4	.287487	0.01	3.74545	8.41
C(S)	0.0	0.00	3.41606	7.67
<u>EC/NC/RDX</u>				
CO	20.3137	40.56	10.9060	24.73
H_2	14.5202	29.00	6.32216	14.34
CH_4	.174395	0.35	3.23304	7.33
C(S)	0.0	0.00	2.86014	6.49

	Gun Calculations		Muzzle Calculations	
	moles/kg of compound	mole % of total	moles/kg of compound	mole % of total
CAB/RDX				
CO	19.3556	39.48	11.1743	25.95
H_2	13.2611	27.05	6.18049	14.35
CH_4	.113754	0.23	3.10807	7.22
C(S)	0.0	0.00	1.74856	4.06
Kraton/RDX				
CO	20.0278	37.46	7.11660	14.32
H_2	16.3990	30.68	6.50579	13.09
CH_4	2.82724	5.29	4.97603	10.01
C(S)	1.70017	3.18	9.46400	19.04
CA/RDX				
CO	18.4082	39.03	12.1359	28.95
H_2	11.1640	23.67	6.26384	14.94
CH_4	.044517	0.09	2.66328	6.35
C(S)	0.0	0.00	.409566	0.98
CTBN/HMX				
CO	21.2010	41.40	7.58801	15.85
H_2	15.2872	29.85	5.74668	12.01
CH_4	1.95237	3.81	3.99536	8.35
C(S)	.415417	0.81	8.80655	18.40

	Gun Calculations		Muzzle Calculations	
	moles/kg of compound	mole % of total	moles/kg of compound	mole % of total
<u>HTPB/HMX</u>				
CO	20.8712	40.15	11.5245	23.51
H_2	15.8320	30.46	8.27901	16.89
CH_4	2.15373	4.14	3.99111	8.14
C(S)	.674326	1.30	6.32798	12.91

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4. Has the information in this report led to any quantitative savings as far as man-hours/contract dollars saved, operating costs avoided, efficiencies achieved, etc.? If so, please elaborate.

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